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Editorial

Why Do We Have So Many Thermal Indices?

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1. Introduction

Ask ten biometeorologists how hot it felt yesterday afternoon and you may receive ten answers, each expressed in a different index. De Freitas and Grigorieva catalogued 165 human thermal climate indices proposed over roughly a century [1] and compared a large set of them in a second paper [2]. Staiger et al. [3] evaluated the most common indices against clear criteria and showed that only a few rest on a complete heat balance of the human body. Earlier reviews reached similar conclusions from the occupational and physiological side [4,5], and the UTCI project compared its new index with many established ones [6].

These papers tell us what indices exist, how they are built and which ones perform well. They say little about why there are so many. De Freitas and Grigorieva [2] touch on it only briefly: they see the large number as a sign of how important the scientific community considers the thermal environment to be for society, and of the wish to quantify it. That is true, but it does not explain why the field did not converge on a few measures, as other fields have. This editorial offers an answer. The deepest reason, I argue, is the complexity of the subject itself. Knowing the reasons is useful, because they also point the way out of the multitude.

2. Seven Reasons for the Multitude and One Underlying Cause

2.1. History and Instruments

The question of how weather acts on people is as old as Hippocrates and his Airs, Waters, Places. Expressing it as a single number is only about a century old, and every index is a child of its time. The effective temperature of the 1920s was derived from people walking between two climate chambers [7]. The wind chill index came from the time it took water to freeze in Antarctica [8]. The wet-bulb globe temperature was designed to stop recruits from collapsing during military training [9]. The predicted mean vote grew out of climate chamber experiments for heating and air conditioning [10], and the heat index out of a detailed model of clothing and skin [11]. Later, heat-balance models of the whole body led to the physiologically equivalent temperature [12,13] and the universal thermal climate index [14]. Each generation used the physiology, instruments and computing power available. New indices were added, but old ones were seldom retired.

2.2. Different Questions

Indices answer different questions. Is a room comfortable? Can soldiers or workers continue without risk? Should the public be warned today? Is a destination pleasant for tourists in May? How does a new square perform in summer? Comfort, stress and strain are not the same, and neither are indoor and outdoor, rest and work, minutes and seasons. An index built for one question is often reused for another, and when it fails, a new one is proposed.

2.3. Available Data

Many indices were built around what weather stations measure: air temperature, humidity and wind. Radiation, the dominant factor outdoors on sunny days, was rarely measured and hard to model until recently.

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Simple temperature–humidity indices flourished because they could be calculated from the data at hand, whether or not they were physiologically sound.

2.4. Climate and People

Indices were developed where the problem was felt. Cold countries produced wind chill measures, hot and humid regions produced sultriness indices such as the humidex [15] and the heat index. People also differ in acclimatisation, clothing and expectations, so even a physically sound index needs regionally adapted assessment scales [16]. Each adaptation can look like a new index.

2.5. Institutions and National Traditions

National weather services, standard bodies and ministries adopted indices and built their services around them: the heat index in the United States, the humidex in Canada, the perceived temperature in Germany [17], the apparent temperature in Australia [18], PET in the German guideline for urban and regional planning [19], the WBGT in occupational standards [20] and the predicted mean vote in indoor standards [21]. Once an index is in law, in software and in public communication, replacing it is costly. The institution keeps the index alive.

2.6. Disciplines

Building engineering, occupational medicine, sports science, meteorology, climatology, geography and tourism research all work on the same human heat balance, but they publish in different journals, attend different conferences and follow different standards. Each community developed its own tools and rarely read the others' literature.

2.7. Incentives

Finally, a new or modified index is publishable. Adding a variable, changing a coefficient or calibrating to a new place yields a new name and a new paper. Some modifications are real improvements, such as the modified PET with a better treatment of humidity and clothing [22]; others add little. Science rewards novelty more than consolidation.

2.8. The Underlying Cause: Complexity

Behind all seven reasons lies a more fundamental one. How a person experiences and copes with the thermal environment depends on a very large number of factors. Weihe [23] ordered the influences on human thermal responses into five system levels, and more than sixty parameters and factors play a role in quantifying the thermal environment [24]. They include air temperature, humidity, wind and short- and long-wave radiation from every direction, but also activity, clothing, posture, body size and composition, age, sex, health, medication, acclimatisation, hydration, time of day, thermal history, expectation, mood and the possibility to move into the shade or indoors. No index can hold all of them. Every index is therefore a reduction, and each reduction reflects a choice about which factors matter for a given question and which can be set to standard values. The wish for simplicity, for one number and ideally for a linear relation between cause and effect, is understandable. Planners, warning services and the public need numbers they can use. But the human heat balance is not linear, and its many factors interact. Where the complexity is reduced differently, a different index results. The multitude of indices is, in this sense, the visible trace of a complex problem that each community simplified in its own way.

The developers of these indices deserve respect. Most indices were built by careful people for a real need, and many of them serve that need well. Simplification is necessary, but it must be conscious: one should know which factors an index includes, which it fixes and which it leaves out, and whether that choice fits the purpose.

3. Discussion

Is the multitude a problem? Partly. It makes studies hard to compare, complicates reviews and meta-analyses, and confuses users who meet different numbers for the same afternoon. For the public, several competing "feels like" temperatures undermine trust in all of them. The problem is sharpened by the fact that many indices share the same physics: PET, UTCI and the standard effective temperature [25] are different outputs of heat-balance models of the same body, while many simple indices ignore radiation altogether and cannot be compared with them at all.

But the multitude is also a sign of health. Different questions need different tools, and no single index can serve a factory floor, a heat warning and the design of a park equally well. The UTCI was an ambitious and successful attempt at a universal outdoor index [14], yet it did not end the proliferation, because the reasons listed

above did not disappear. Institutions keep their indices, data limitations remain in many parts of the world, and new applications keep appearing.

The reasons also point to the solution. If indices multiply because a complex problem is simplified in many ways, and because of history, institutions, disciplines and incentives, then another index will not help. What helps is a clear choice for a clear purpose: the purpose decides the means. Staiger et al. [3] proposed criteria for this choice, and they can be turned into simple questions. What is the question, and who is the person (activity, clothing, vulnerability)? Indoor or outdoor, minutes or seasons? Which input data are available, and is radiation included? Is there a validated assessment scale for the region? Answering these questions usually leaves only a handful of candidates, most of them based on a complete human heat balance. The historical indices remain valuable for continuity and for comparison with older studies, but they should be used knowingly.

In the end, the indices are about people. People do not need 165 indices. They need one clear message for today and one sound basis for planning tomorrow's cities. The scientific community can provide both only if it explains its tools, reports the inputs behind every value and resists the temptation to add number 166 without good reason.

4. Conclusions

We have many thermal indices because the human thermal environment is shaped by a large number of interacting factors that every index must reduce in its own way. The field also grew over a century, across disciplines and countries, around different questions, data and institutions, and novelty has always been rewarded. The multitude is understandable, deserves respect and is partly useful, but it needs order. The way forward is fitness for purpose rather than another index: a clear question, a transparent choice among the few well-founded indices, and honest reporting of what each number means for the person standing in the weather.

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